Villanova University ASV Team

SeaCat

AUVSI Roboboat Competition 2012 Journal Paper

The Villanova University autonomous surface vehicle team will be debuting SeaCat at the 5th Annual Roboboat Competition. SeaCat is completely new this year with twin fiberglass hulls and a PVC frame. It is equipped with two thrusters and a seamless differential drive. A Speedgoat Real-Time module, running Mathworks xPC Target, controls everything onboard completely autonomously.

For this year's competition, SeaCat must demonstrate strength, speed, and obstacle avoidance. Then SeaCat must identify a series of targets and shoot, press, retrieve or report position of the target, testing its identification, control and communication skills. SeaCat must be able to travel through waterfalls in order to reach a target, to show its water-hardiness. Also, a subsystem must be deployed to retrieve one of the targets, demonstrating intersystem compatibility. All of these tasks must be accomplished while playing a game of Five Card Draw against the judges.

1. Introduction

An autonomous surface vehicle (ASV) is a robotic boat designed to complete a variety of tasks in a completely independent manner. There are many advantages to autonomous vehicles, such as keeping human life away from dangerous situations and hazardous environments. The challenge is designing the craft so that it can maneuver under its own control and to make decisions without the need for outside intervention. The AUVSI Roboboat competition was conceived to encourage students to start working on real-time application of autonomous technology to advance the field.

2. The Mission

The theme of this year's competition is "The Five Card Draw." At the beginning of the mission, the vessel must complete a weigh-in and remote-operated thrust test. Then the vessel will have twenty minutes to complete a series of tasks autonomously. First,the boat must demonstrate its speed through start and stop gates and then demonstrate its dexterity by navigating a buoy channel and avoiding obstacles. Once through the buoy channel, there are a number of challenges to be completed. First is the Poker Chip, where the boat must dock and release a subsystem to retrieve a poker chip. Next is the Jackpot where the vessel detects the "winning" post and pushes the appropriate button. Then is the Cheater's Hand, where a target must be identified and shot. Finally The Hot Suit, where a hot target is identified and reported. At each of these stations is the Card Exchange where the vehicle has a chance to try its luck and play Five Card Draw.

3. Design Overview

The main design foci for SeaCat were to maintain a low weight, create a high level of maneuverability, and to have centralized processing. A complete redesign of last year's vessel traded a single hull for a catamaran-style double hull, a singular drive system with a swiveling propeller for a differential drive, and a Pathways Pelican PC 104 for a streamlined Speedgoat Mobile Real-Time Target Machine.

3.1 Boat Structure

The new hull design, shown in Figure 1, is designed to be light weight and durable. A double hull design was chosen to provide better stability in roll and yaw. The hulls are identical in principle, fashioned out of the same mold.

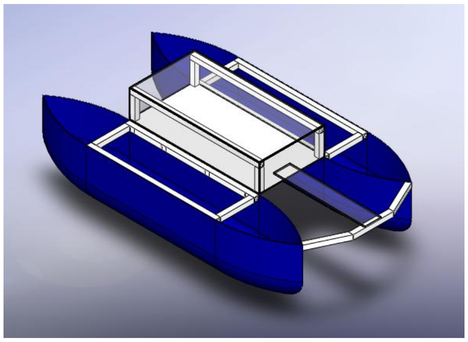

Figure 1: CAD Model of SeaCat Hulls

The hulls are made of hand-laid fiberglass. The process used by the team is as follows. First a foam plug was carved to design specifications, and then a plaster mold was formed from this plug. Using the plaster mold, the team laid three layers of 10oz fiberglass cloth to make each hull, as shown in Figure 2. Each hull is 50 inches long, 20 inches tall and 8 inches wide. When assembled with a 12 inch wide center platform, the total width is 29 inches.

Figure 2: Team Fiberglass Layup

Fiberglass was chosen because of its low weight to strength ratio. Due to the rigidity of the material and the chosen shape of the hull, little support structure was needed, cutting down on weight. This design change has SeaCat weighing in at 69 lb, far below our competition weight of 128 lb last year.

The frame of SeaCat is built from 0.875 inch square PVC tubing. This material was also chosen for its low weight to strength ratio. The square shape of the tubing allowed for solid connections and easy alignment. The structural tubes that hold the two hulls together also act as power conduits, creating watertight pathways for wires to be run between hulls while maintain a high level of order among the wires.

3.2 Power System

SeaCat is powered by two Tenergy 12.8V LiFePO4 batteries in series, providing a maximum of 25.6V. This voltage is then regulated to 12V and 5V to power all of the systems on the boat. With a total of 20Ah available, SeaCat can run for about 8 hours before needing to be recharged.

Two Seabotix BTD150 thrusters are attached to the bottom of each hull, positioned ¾ of the way to stern. Controlling the motors are two Sabertooth

2x25 V2 H-bridge motor controllers connected to either 12 or 25.6VDC. The controller receiving 12V takes in analog signals from the control box and the 25.6V controller receives PWM signals from the RC receiver. The separate motor controller allows for RC control to not only be always available, but also gives RC a master override over automatic control for greater safety.

3.3 Sensors

Real time sensors on the boat include a Logitec Pro 9000 webcam, a Honeywell HMR-3000 Compass Module, a Garmin 18x5 Hz GPS, an Omega OS-ST8855W infrared thermometer, and ultrasonic sensors. The integration of each sensor will be described in the following sections through its use in the specific tasks.

4. Tasks

During the competition, SeaCat will have to complete a number of tasks. SeaCat must first navigate a buoy channel, and then find its way to four task stations. At each station, SeaCat will have the option to exchange cards and play poker. The first station is the Poker Chip, an amphibious landing, followed by The Jackpot, a target identification and waterproofing test. Then, the Cheaters Hand and Hot Suit will be attempted, in which a target is identified and accordingly shot or reported.

4.1 Buoy Navigation

The most process intensive part of this task is buoy detection. Buoy detection will be accomplished using the onboard vision system. Images are acquired using a Logitec Pro 9000 webcam and processed using custom code written with help from the Matlab Computer Vision libraries. To detect blobs of red, green, and yellow, the incoming image is compared to a color threshold, which is calibrated for different lighting conditions. A blob analysis algorithm is then performed on the resulting binary image. From the blob analysis, important features such as centroid, area, and extent (the ratio between the area of the blob and a surrounding bounding box) are obtained. Comparing these features, the ASV can identify any given blob as being a buoy or not a buoy (Figure 3). Once a buoy is detected, the angle to that buoy can be found and an appropriate heading is passed onto the steering controller. That heading is dependent upon whether one or two buoys are found. If no buoy is found, a search algorithm will commence where SeaCat turns in place to scan the local area and determine potential buoys. Once a buoy is found, SeaCat can continue its course until it completes the buoy channel.

Figure 3: Buoy identification

4.2 The Card Exchange

This task requires SeaCat to play 5 Card Draw. SeaCat will be delt five cards at the beginning of the run. Next to each task station will be a board with playing cards magnetically attached to it. SeaCat must exchange cards with the board. To accomplish this, a robotic arm with an electromagnet has been built. The arm, modeled in Figure 4, is mounted on the upper deck of SeaCat. The arm has four driven degrees of freedom. The base of the arm swivels left and right and the three 1 ft links of the arm provide forward and vertical motion. On the end of the arm is an electromagnet that is used to remove the cards from the exchange board. The card is brought in front of the camera to be read and, based on the rules of poker, the boat will decide which card to discard next.

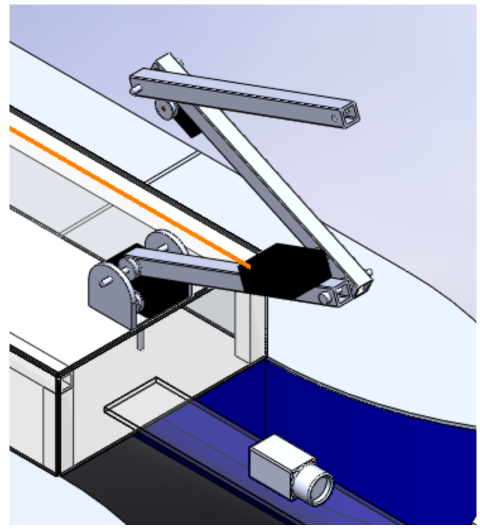

Figure 4: Robotic Arm on SeaCat, CAD model

4.3 The Poker Chip

For this station, SeaCat must dock with the landing zone and release a subsystem to retrieve a hockey puck covered in Velcro. SeaCat will deploy its subsystem through the use of is robotic arm, holding the top of the subsystem with the electromagnet. The subsystem, entitled CLAWdia, is controlled by an Arduino Atmega328P. Shown in Figure 5, CLAWdia is outfitted with two ultrasonic sensors and a servo controlled claw.

One ultrasonic sensor is pointed down to make sure that there is solid ground in front of CLAWdia before it moves forward in order to ensure it does not fall off the platform. The other ultrasound is oriented parallel to the ground and is used to locate the puck. Once the puck is within range, CLAWdia's claw will close, SeaCat will be alerted and the subsystem will be pulled back to SeaCat via a winch system.

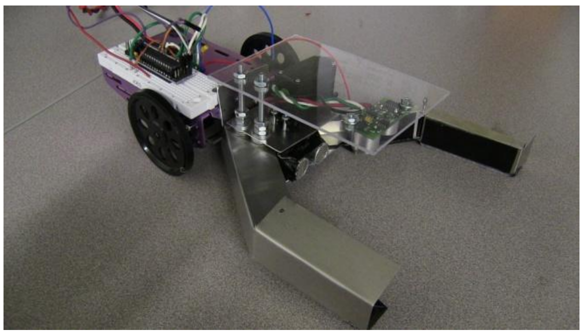

Figure 5: Subsystem CLAWdia

4.4 The Jackpot

In this task, SeaCat must locate and push a red button that is marked by an underwater white polyform buoy. Once the button has been pushed, a water fountain will be activated. This task will test SeaCat in two ways. First the vision systems and algorithms are tested to locate both the red button and the submerged buoy. Once the button is identified, the aforementioned robotic arm will be positioned to press the button. Second, the waterproofing is tested by the fountain. This aspect of the task is most dangerous as a small leak in the wrong place could prove disastrous to the onboard computer. Thus great care has been taken to ensure that water will not invade the control enclosure during this task.

4.5 The Cheaters Hand

For this task, SeaCat is required to locate a fake card, marked by a blue square, and shoot the card with water. Using video detection very similar to that discussed in Section 4.1, a blue square will be located within a white box. Once the target has been located, the previously mentioned robotic arm will be raised and aimed. At the end of the arm is a nozzle that will focus water into a $1/8^{th}$ inch stream. The water is being pumped from the lake at 1 gpm by a Flojet LF-12 Series 12V automatic pump. This flow rate was chosen to allow for easy control and aiming of the water stream.

4.6 The Hot Suit

For this task, SeaCat must locate a hot target and report to shore which playing card suit is printed on the hot target and the target's location. To do this, SeaCat has been outfitted with an Omega OS-ST8855W infrared thermometer and a Garmin 18x5 Hz GPS. Using video recognition, each of the four targets is identified as either red or black. Then the red targets are identified as either hearts or diamonds and the black targets are identified as spades or clubs. Once the targets are known, they are scanned with the IR gun in order to identify which is hot. Then, using a GPS projection algorithm, SeaCat is able to determine the GPS position of the target based on SeaCat's own position. The position and suit of the hot target is then transmitted to the competition server via the established wireless network.

4.7 Return to base

Once SeaCat has completed all of its tasks, it must return to dock. This will be done through GPS navigation. On its way through the buoy channel the first time, SeaCat will log GPS points. On the way back, using the Honeywell HMR-3000 Compass Module in conjunction with the Garmin GPS, SeaCat will follow the map it made for itself in order to ensure a safe return.

5. Computer and Software Design

The main processing power for SeaCat comes from the Speedgoat Mobile real-time target machine. This real-time machine offers analog and digital I/O as well as PWM signals. It is also used to read in serial data from onboard sensors. One important feature of the Speedgoat machine is that it is capable of video acquisition (via webcam) as well as vision processing all on a single board. Having all capabilities centralized in this device eliminated cross-device communication issues that plagued previous ASVs. Speedgoat works as a target machine through Mathwork's Simulink via xPC Target.

5.1 High Level Control

The backbone of SeaCat's software architecture is a Finite State Machine (FSM). Each task (e.g., buoy channel, Cheater's Hand) is considered a separate state. Once one task is completed, a signal is sent onto the next task, which will trigger a new subroutine (and disable the previous task) based on the objectives of that particular task. The signal is dependent on specific criteria for each task. For example, the cheater's hand station is recognized as completed once the red flag is raised.

Because each task is heavily dependent on video recognition and navigation, it is necessary to supply video input to each task. That image is only processed and transmitted by the task currently enabled, which ensures an optimal use of processing power. With this FSM in place, the video processing algorithms are tailored for each task. For instance, one video algorithm can be used in the buoy navigation task while another algorithm can be used to detect card suits in the hot suit challenge.

5.2 Low Level Control

When enabled, each task supplies desired heading and propulsion based on what is appropriate for that task. These values are passed onto heading and propulsion controls. To output a desired rpm, the value specified by each task is scaled to a voltage output to be sent to then read by the motor controller. This is shown graphically in Figure 6. SeaCat navigates to its desired location after it is given a heading to follow from the enabled task block. The current heading is resampled by the compass every 0.1 seconds and is input to a PD feedback controller enabling the ASV to quickly and accurately reach its desired heading value. The output from the controller is likewise scaled and sent to the motor controller. The heading controller was calibrated in early water tests to determine optimal controller gains. Low PD gain values proved most efficient to limit oscillation and respond appropriately to video based navigation.

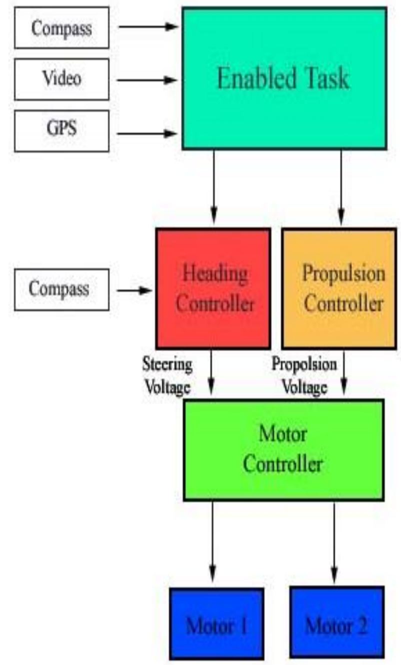

Figure 6: Low Level Control Diagram

6. Conclusion

SeaCat is a fully autonomous water craft designed and built by Villanova University's ASV Team. SeaCat has undergone countless hours of dry land and wet testing at the Villanova Conference Center lake in order to tune the navigation systems and calibrate video thresholding. After much hard work, SeaCat is ready to compete in the 5th Annual Roboboat Competition. We are proud of what this team has accomplished through SeaCat, and we are confident going into the competition.

7. Team and Advisors

We would like to thank our entire team for all of their hard work and our advisors for their outstanding guidance.

7.1 Team

Joseph Denny- BSME ’13

Nick DiLeo– BSME ’13 Team Leader

Ryan Holihan – BSME ’12

Shahriar Khan – MSEE ’13

Lester McMackin – BSME ’13

Alex Poultney – BSME ’14

Mike Weber – BSCPE ’13

7.2 Advisors

Dr. C. Nataraj

Dr. Helen Loeb

Dr. DongBin Lee

Dr. Garrett Clayton

Ralph Sullivan, MSME ‘12